for a second time. It is interesting to note that the upheaval of the Exploring Isles, by which the previously extinguished Trigger reef became resurgent, was of a significantly earlier date than the resurgence of Frost reef between Mango and Vatu Varâ; for the limestones of these two islands are little dissected, while those of the Exploring Isles have been eroded to mere remnants of their former volume. It is the present almost-extinction of Trigger rock in a renewed subsidence of its region that is contemporaneous with the resurgence of Frost reef. Darwin's theory of intermittent subsidence is the only one of many coral-reef theories, which can account for the facts here adduced.

THE ORIGIN OF CERTAIN FIJI ATOLLS

By W. M. Davis

DEPARTMENT OF GEOLOGY AND GEOGRAPHY, HARVARD UNIVERSITY

Received by the Academy, June 22, 1916

The unconformable contact of many fringing reefs on the eroded submarine slopes of oceanic islands, and the embayment of such islands inside of barrier reefs are inconsistent with certain modern theories of coral reefs; and the recognition of these significant features has in recent years led several observers back to Darwin's earlier theory of upgrowth on intermittently subsiding foundations. My own experience two years ago, while on a Shaler Memorial voyage across the Pacific concerning which a brief report has been published in these PROCEEDINGS (**1**, 1915, 146–152), added evidence of reef formation during two periods of subsidence; the first subsidence being shown by the occurrence of elevated reef limestones resting unconformably on eroded volcanic foundations, as seen in Vanua Mbalavu and Avea, two of the reef-encircled cluster of the nine Exploring Isles in the eastern part of the Fiji group, the second subsidence being shown by the embayment of these now-dissected limestones, around which a new barrier reef has grown up, as stated more fully in the *American Journal of Science* for September, 1915.

Continued attention to this problem has lately enabled me to perceive that the evidence of two periods of subsidence and reef growth found in the Exploring Isles may be extended to several neighboring atolls, the area concerned being well shown in Plate 19 of Agassiz' "Islands and Coral Reefs of Fiji" (*Bull. Mus. Comp. Zool.*, xxxiii, 1899): thus singularly enough a reconciliation is permitted between Agassiz' theory of the formation of atolls on uplifted and worn-down limestone islands and Darwin's theory of the formation of atolls by upgrowth on

subsiding islands. But it is not intended to imply that the view here announced applies to all atolls of the Fiji group, much less to all atolls elsewhere, most of which have probably been formed by upgrowth during intermittent subsidence without important interruption by uplift.

The essence of the case is as follows: In the Exploring Isles of the Fiji group, a portion of the largest volcanic island, Vanua Mbalavu, of well denuded form, 13 miles long and 930 feet high, is shown in the apex of sector M, figure 1; it is in part unconformably covered up to heights of 500 or 600 feet with heavy reef and lagoon limestones, deeply dissected and well embayed. Avea, a smaller member of the same cluster, two miles long, capped with limestones resting unconformably on denuded volcanic hills, rises 600 feet from the same broad lagoon,

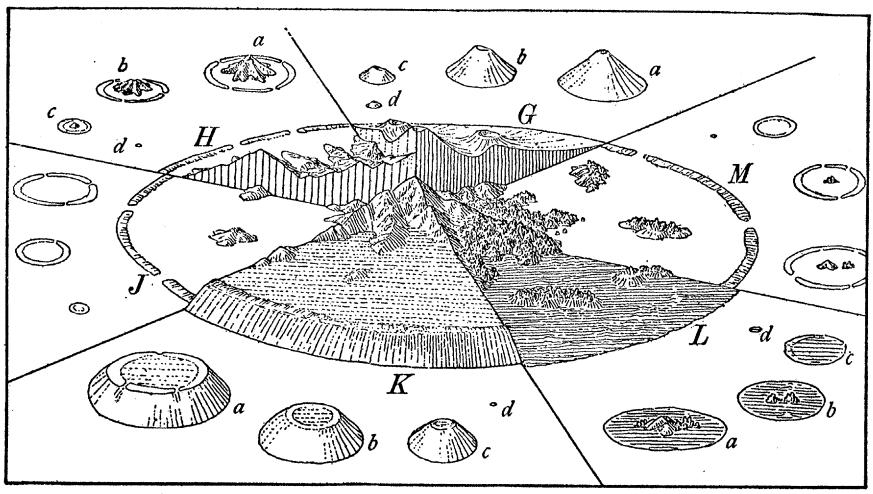

FIG. 1.

and is enclosed with the eight other Isles of the cluster by an irregular barrier-reef ring, 23 miles in longest diameter, part of which is shown in the same sector. All but one of these islands consist partly or wholly of elevated limestone: they therefore presumably represent, as Agassiz points out, "fragmentary remains of the land which must have once occupied the area of the lagoon." Outside of the barrier reef, twelve almost-atolls, atolls, and isolated reef patches rise from deep water, not more than 5 or 10 miles distant: four of these are represented in sector M: an almost-atoll in which the small central rocks are partly volcanic, partly limestone; a smaller almost-atoll, with limestone rocks alone rising from its lagoon; a true atoll; and a small reef on the verge of extinction. The islands and reefs are crowded together in the diagram to save space: the circular pattern which the barrier reef of the Explor-

ing Isles here seems to have results from the repetition of one sector in six successive positions: the reef is really of irregular pattern and the islands are not centrally placed within it. A consideration of all the pertinent facts shows that, if the strong changes of level demanded by Vanua Mbalavu and Avea have extended to the exterior atolls, as is eminently probable, then the true atoll and the almost-atolls have been formed, during a recent subsidence of a few hundred feet, by upgrowth on the worn-down remnants of uplifted atolls, which had likewise been formed by upgrowth, presumably on a volcanic foundation, during an earlier time of greater subsidence.

The changes of level demanded by Vanua Mbalavu and Avea may be inferred from the structure of Avea, two miles long and 600 feet high, as shown in part in figure 2. It should be announced that this figure has been drawn from a rough outline made from a passing steamer; confidence is nevertheless felt in its essential correctness, for I fully agree with Gardiner and Agassiz that volcanic slopes and limestone cliffs in the Fijis are easily recognized at a distance. The under-

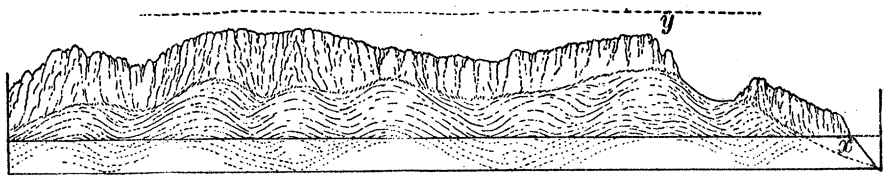

FIG. 2.

lying volcanic rocks here, as in Vanua Mbalavu, have the forms of rounded hills, subdued by deep erosion before they were covered with limestones. The eroded slopes dip under water, as at x; hence the island formerly stood at least x feet higher than now. The subdued hills and slopes are partly covered by limestones, now rising to a height of 600 feet; the limestones have suffered much erosion, which has greatly diminished their area, and has somewhat reduced their height, as at y. Hence the island after being eroded, must have sunk $x + 600 + y$ feet while receiving its unconformable limestone cover. The limestones are now dissected and their shore line is so well embayed as to necessitate a recent submergence of more than 100 feet; and it must have been during this submergence that the present great barrier reef has grown up. It may be noted in passing that the postglacial rise of ocean level may have had to do with the recent submergence, but for reasons elsewhere stated I believe that true subsidence has also been concerned in it.

The six sectors, G to M, of figure 1 graphically represent the succes-

sive changes thus inferred. Sector G shows part of a group of confluent volcanoes, the area of which is about the same as that of the present Exploring Isles lagoon; several smaller cones rise near by; all together they resembled the present Lipari islands of the Mediterranean. After suffering prolonged dissection and partial submergence, the resulting embayed islands encircled by an upgrowing barrier reef are represented in sector H; this stage corresponds to that of Kandavu and its neighbors in southwestern Fiji. Down-sinking of the volcanic islands and upgrowth of the barrier reef continued until the total subsidence measured $x + 600 + y$ feet, when but few volcanic hills survived, as in sector J; the small Gambier islands in a large lagoon southeast of the Paumotus, or the small islands of Budd reef in northeastern Fiji represent this stage. An uplift of $600 + y + > 100$ feet then occurred, as in sector K: the resulting limestone plateau is typified by the uplifted atolls of the Loyalty group. The compound mass thus exposed to erosion was reduced over most of its limestone area to low relief surmounted here and there by residual hills, as in sector L; the hills of volcanic rock have smooth soil-covered slopes, those of limestone have steep cliffs and ragged crags. A recent submergence of 100 feet or more introduced the present conditions, as in sector M, where the lagoon floor has been smoothed by renewed deposition.

The exterior volcanic islands, a, b, c, d, of sector G, must have suffered essentially the same series of changes as the larger central volcanic islands. The atoll built on the largest cone, a, may have shown no volcanic knob in the stage of sector J, but one is afterwards laid bare in sector L, and its summit remains visible, along with a limestone knob, in the largest reefring of sector M. Island b having a less initial height in sector G, it now shows only limestone knobs, sector M. Island c, beginning as a small volcanic cone, sector G, was deeply covered with limestone in sector J, and reduced to a low surface without high limestone knobs in sector L; and this is reasonable enough, for its area is not so large as any one of several uninterrupted lagoon areas within the adjacent great barrier reef. Its present reef is the result of upgrowth during the subsidence which transformed sector L into sector M.

Seven of the twelve outlying reefs near the Exploring Isles are true atolls, like the true atoll of sector M. The foregoing discussion gives, I believe, a nearer approach to a demonstration of the origin of these sea-level atolls by upgrowth during sub-recent subsidence than has been provided for any other sea-level atolls, except Funafuti which has been penetrated by a deep boring. The smallest reef in sector M

represents mere ledges of coral rock on the Admiralty chart: the 100-fathom line around each of three such reef rocks near the Exploring Isles is less than a mile in diameter, and the rocks are mere points; hence these minute reefs, beginning on small volcanic cones in the stage of sector G, must have been extinguished in sector J, resurgent in sector K, a little enlarged by outward growth in sector L, and almost extinguished again in sector M.

The upheaval and the sub-recent subsidence mentioned in the foregoing paragraph were not uniform, as has thus far been implied. The recent subsidence is believed to have increased to the east or northeast; first, as Agassiz pointed out, because the floor of the great lagoon of the Exploring Isles increases in depth from 20 fathoms or less on its western side to 80 or 100 fathoms on its eastern side; second, because several 'drowned atolls' or submerged banks lie to the northeast; indeed the northeastern-most of the seven outlying atolls is mostly submerged; third, because Mango, 10 miles to the southwest, has elevated reefs moderately dissected at an altitude of 500 feet, and 30 miles to the west, Yathata and Vatu Varâ are uplifted, undissected atolls at altitudes of 840 and 1030 feet. The intermediate island of Kanathea, nearer to the Exploring Isles barrier reef than Mango is, also seemed to me to bear small uplifted reefs at a height of about 600 feet, but I was too far from this island to make sure of it.

The upheaval that preceded the subrecent subsidence must also have been unequal and greater to the east than to the west, because while the Exploring Isles were thus uplifted long enough ago to have been afterwards well dissected, Yathata and Vatu Varâ were at that time presumably sinking and growing, preparatory to being uplifted recently as above stated. These unequal changes of altitude cannot be explained by changes in the level of the ocean, which are everywhere alike; they can be explained only by unequal subsidence and upheaval of the islands concerned.

INTERFEROMETER METHODS BASED ON THE CLEAVAGE OF A DIFFRACTED RAY

By C. Barus

DEPARTMENT OF PHYSICS, BROWN UNIVERSITY

Received by the Academy, June 20, 1916

The prismatic method of cleaving the incident beam of white light is available for the superposition of non-reversed spectra, under conditions where the paths of the component rays may have any length whatever.